Research on the Effects of Hole Size on Borehole Stability

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Abstract

Sidewall instability will affect drilling speed and the efficiency of development, and even lead to the purpose of exploration and development unaccomplished, which results in huge economic losses for the exploration and development of underground resources. To reduce the risk of wellbore instability and cut down development costs of underground resources, this paper adopted numerical simulation method to analyze changes in wall rock pressure, displacement field and velocity field under different borehole radius conditions. Studies have shown that: the rock pressure and flow rate decrease with the increase of hole size, and the change rate of the fomer is relatively slow, however the later is more obvious, displacement increases as the size of the hole increases, and the increasing trend is more significant. The research of this issue has apractical and significant guidance for choosing reasonable hole radius, improving the stability of borehole, and reducing the cost of the exploration and developmet of underground resources.

Keywords

Borehole size, Borehole stability, Surrounding rock stress, Displacement field, Velocity field.

1. Introduction

Since there are many factors affecting borehole stability, wellbore instability problem has always been difficult to solve in drilling engineering. And researchers have done a lot of research work in the wellbore stability analysis, achieving considerable progress. In 1990, Gray and Darly analyzed the basic principle of the shale hydration effect on borehole stability, improving the relevant information and test data required for wellbore stability analysis [1]. In 1997, Chee P.T., Brian G.R. studied the influence of shale swelling and hydration on borehole stability [2]. In 2003, Chen G., Chenevert M.E., Sharma M.M. et al [3] analyzed the influence of porous elastic, chemical and heat transfer on the borehole stability.

In 2011, Kang Q., Mian C., Yan J. et al. [4] studied the variation of rock mechanics parameters and the distribution of rock stress distribution around the well after acidification, lerrning the influence of acidification on borehole stability. Lee H., Ong.S.H, Azeemuddin M. et al. [5] analyzed the influence of rock strength anisotropy on borehole stability. Liu Jianjun, Huang Xiaolan, in Xian Bin [6-10] studied the dynamic evolution of perforating the well borehole rock stress field, simulated the equivalent stress of open borehole of bedded salt strata, and analysed the influence of water, pressure relief and different injection-production ratio on wall rock stress, pore pressure and stress. In 2015, Gholami R., Rasouli V., Aadnoy B. et al. [11] analyzed the wellbore stability of isotropic and anisotropic conditions through in situ stress assessment methods. Le ping et al. [12, 13] established coupling model for reservoir percolation and flow using reservoir subdivision method, and had a comprehensive analysis of the effects of fluid-structure coupling on borehole stability. Majed F. Kanfar, Z. Chen, SS Rahman[14] explored the window density of safe drilling, giving isotropic and anisotropic rock stress distribution analytical solution, and the anisotropic formation borehole instability risk control was analyzed. WANG Jianwei et al. [15] built mathematical model to analyze the effects of the mud pressure and pore pressure on the borehole stability.

The above research mainly studied the influence of wall stress distribution, mechanical factors, such as the magnitude and direction of situ stress, chemical factors and drilling fluid density on borehole stability. The research starting from the influence of bore size on borehole stability is relatively few. Most are based on size effect of rock strength, which established a prediction model of the influence rule of hole size on the borehole collapse pressure and fracture pressure, and borehole stability of slim hole and tiny hole were studied. Li Wenkui, He Shiming[16-17] analyzed the development status of slim hole drilling technology and some existing problems, and studied the development of slim hole drilling technology, developing appropriate measures to form a complete optimization technology; in the meantime, they concluded that using the small hole can significantly reduce drilling collapse pressure through the comparison of collapse pressure of standard wells and small borehole changing with wellbore trajectory.

This paper researched the change of borehole rock stress, displacement field and the velocity field by changing the size of the hole. And the influence of hole size on the stability of borehole are acquired.

2. The mathematical model of borehole stabilitys

For there are many complex factors affecting borehole stability, such as situ stress, formation pore pressure, and fluid column pressure in the well, constitutive characteristics of rock and so on. What's more, constantly erosion of drilling fluid and wellbore temperature field changing also have influence on borehole. Therefore, before the study of the problem, it is necessary to do the following basic hypothesis on the model [18]:

Strata is homogeneous and isotropic;

In each specific analysis, the temperature remains constant (ignoring the effects of temperature field);

The global coordinate axis is parallel to the direction of the principal stress;

Ignoring chemical factors(drilling fluid);

Fluid is a stable Darcy flow.

2.1 The three dimensional stress-strain control equation

The control equations of three dimensional stress-strain are as follows [18, 19]:

$$(\lambda+G)\frac{\partial\varepsilon}{\partial x}+G\nabla^2 u+F_x=0 \tag{1}$$

$$(\lambda+G)\frac{\partial\varepsilon}{\partial y}+G\nabla^2 v+F_y=0 \tag{2}$$

$$(\lambda+G)\frac{\partial\varepsilon}{\partial z}+G\nabla^2 w+F_z=0 \tag{3}$$

Where: ε -volumetric strain; F_x, F_y, F_z -the volume force;

$\nabla^2=\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}+\frac{\partial^2}{\partial z^2}$; G, λ -Lame constant, defined as follows:

$$G=\frac{E}{2(1+v)} \tag{4}$$

$$\lambda=\frac{vE}{(1+v)(1-2v)} \tag{5}$$

Where: E-Young's modulus; v -Poisson's ratio.

2.2 The describing equations of fluid

Fluid in the rock pore is a stable Darcy flow, the change of fluid pressure can cause the elastic displacement of rock stratum, and a continuity equation was introduced to describe the fluid flow [18]:

$$\nabla \bullet \left[-\frac{k}{\psi} \nabla p \right] = 0 \tag{6}$$

Where: k -permeability coefficient, cm/s; ψ -fluid viscosity, Pa.s; p -pore water pressurein the rock, Pa.

2.3 solid deformation equation

Solid deformation equation is [18, 20]:

$$-\nabla \bullet \sigma = F \tag{7}$$

Where: σ -Stress tensor, Pa; F-external forces on rock, N.

3. Numerical Simulation

3.1 Introduction of the model

This problem belongs to the fluid solid coupling problem. Fluid flow with the Darcy's law, coupled with the structural displacement of the stress-strain analysis. Therefore, the model is bulit by using the elastic model of structure, and the steady state analysis has been done. Taking the finite element discretization error and calculation error into account, calculation range of the study should be about more than 5 times the diameter of the hole in order to ensure the necessary calculation accuracy. So, the length and width of the model is 5m, the thickness is 2.5m in this paper, and the geometric size and the mesh are shown in Figure 1:

The parameters used in the modeling progress mainly refer to the parameters of reference [21, 22], the value shown in Table 1:

Table 1 Main parameters and values

Rock parameters	Value	Rock parameters	Value	Rock parameters	Value
Biot-willis coefficient	1	Porosity	0.3	Density(kg/m^3)	998
Density(kg/m^3)	1450	Permeability（mD）	0.8	Dynamic viscosity（Pa*s）	8.8
C(MPa)	10	Young's modulus(Pa)	3	Fluid compressibility（%）	2.6
φ ($^\circ$)	25	Poisson's ratio	0.26	Borehole fluid column pressure(MPa)	18

The size of the hole will affect the borehole collapse pressure, fracture pressure and density range of drilling fluid, thus affecting the overall stability of the borehole.

Therefore, the change law of the surrounding rock pressure, displacement field and velocity of the horizontal in the drainage process are studied in this paper by changing the radius of the hole, the size of the hole are 0.2m, 0.4m, 0.6m, 0.8m and 1.0m.

3.2 The simulation results analysis

When the borehole diameter is 0.5m, the displacement change of wall rock, the pressure distribution, the fluid pressure and the flow field distribution in the process of oil and gas drilling of horizontal well are shown in Figure 2, Figure 3, Figure 4 respectively:

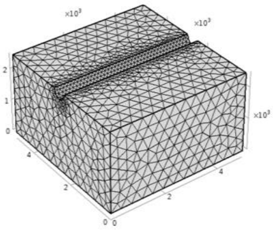

Fig. 1 The geometry and meshing of the model

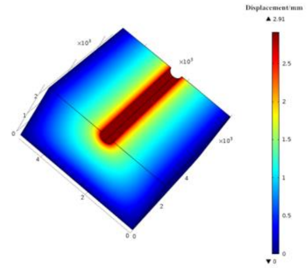

Fig. 2 Displacement of surrounding rock

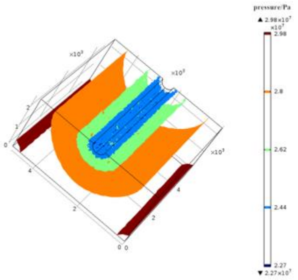

Fig. 3 Stress level of surrounding rock

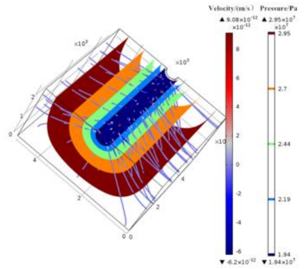

Fig. 4 Distribution of fluid pressure level

From Figure 2 we can see, the closer to the borehole, the greater the total displacement of surrounding rock is, and the farther, the smaller is; in the process of nearing the borehole, surrounding rock pressure and pressure of the fluid flow are decreaing, derived from Figures 3 and Figure 4; also it can be seen from Figure 4, velocity of fluid increases gradually in the process of flowing.

During the exploitation of oill storage well, as the change of the hole size, the displacement curve, the pressure curve of surrounding rock and fluid velocity curve near the borehole are respectively shown in Figure 5, Figure 6 and Figure 7:

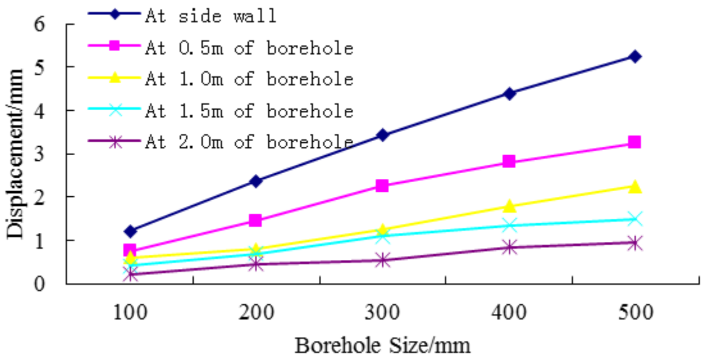

Fig. 5 Displacement curve of surrounding rock along with the change of the hole size

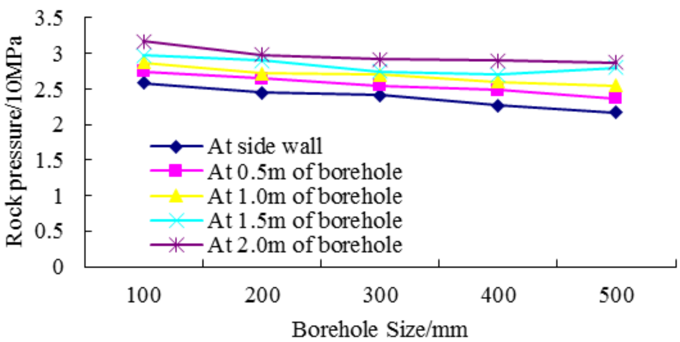

Fig. 6 Pressure curve of surrounding rock along with the change of the hole size

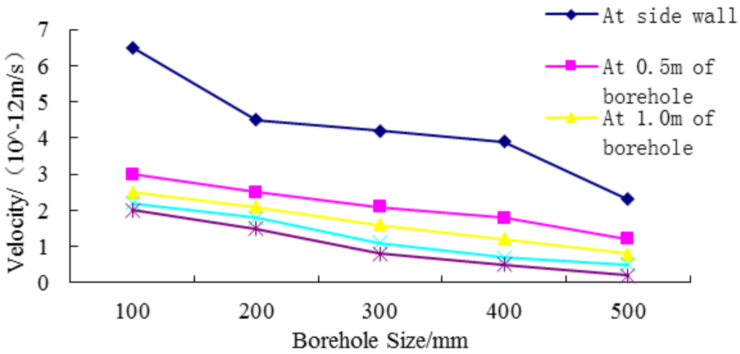

Fig. 7 Velocity curve along with the change of the hole size

It can be seen from Figure 5, the total displacement of wall rock is increasing with the increase of the radius of the borehole, the closer to the wall, and the greater the rate of displacement of surrounding rock is. When the radius of the borehole changes from 0.1m to 0.5m, the total displacement of surrounding rock rises from 1.22mm to 5.25mm. And when the distance from the wall is 2m, the total displacement of surrounding rock changed from 0.22mm to 0.95mm. The displacement of surrounding rock increased at a rate of 0.8%, which is about 5.3 times the rate 0.15% that at 2m of the wall. It can be derived from Figure 6, with the size of the borehole increasing, pressure of surrounding rock shows a decreasing trend, and however, the changes are relatively slow. When the radius of borehole rises from 0.1m to 0.5m, the pressure of surrounding rock reduced from 25.8MPa to 21.7MPa, also, the pressure of surrounding rock where distanced from wall are 2m changed from 31.7MPa to 28.7MPa; from Figure 7, we can see, the closer to the wall, the greater the velocity is, and the farther , the smaller is. With the increase of the radius of borehole, the flow velocity of fluid decreases gradually; the closer to the wall, the more evident the changing trend is. When the radius of borehole rises from 0.1m to 0.5m, the velocity nearing wall changed from 6.5m/s to 2.3m/s, the velocity where dictance from wall are 2m decreased from 2m/s to 0.2m/s, the change rate of former is faster about 2.3 times than the later.

4. Conclusion

The process of mining oil and gas resources involving many complex problems, such as fluid seepage and solid deformation field coupling, through modeling, coupled analysis of the issue, and obtained the influence law of the hole size change on surrounding rock stress and displacement field and velocity field.

The displacement of surrounding rock increases with increase of hole radius, and the closer to wall, the increase rate of displacement of surrounding rock increase faster, and the more close to the wall, the greater the displacement of surrounding rock; When the radius of borehole rises from 0.1m to 0.5m, the displacement of surrounding rock increased at a rate of 0.8%, which is about 5.3 times the rate 0.15% that at 2m of the wall.

With the increasing size of the borehole, rock pressure were tested decreasing trend, but changes are relatively slow, and the farther away from the wall the greater the rock pressure, the closer, the smaller.

As the hole radius increases, fluid seepage velocity decreases, The closer to wall, the change trend more obvious, and the closer to the hole, the greater the velocity, the farther the smaller. While the osmotic pressure is on the opposite. When the radius of borehole rises from 0.1m to 0.5m, the change rate of the velocity nearing wall is faster about 2.3 times than that at 2m of the wall.

References

[1] Fleming N H, Ronaldi R, Bruce S, The application of" mechanical" borehole stability theory to development well planning[Z]. Society of Petroleum Engineers, 1990.

[2] Chee P T, Brian G R. Effects of swelling and hydration stress in shale on wellbore stability[J]. SPE38057. 1997.

[3] Chen G, Chenevert M E, Sharma M M, et al. A study of wellbore stability in shales including poroelastic, chemical, and thermal effects [J]. Journal of Petroleum Science and Engineering. 2003, 38(3–4): 167-176.

[4] Kang Q, Mian C, Yan J, et al. Stability model of borehole wall during the well test after acidizing treatment of sandstone reservoirs[J]. Petroleum Exploration and Development. 2011, 38(5): 589-593.

[5] Lee H, Ong S H, Azeemuddin M, et al. A wellbore stability model for formations with anisotropic rock strengths[J]. Journal of Petroleum Science and Engineering.2012, 96: 109-119.

[6] Liu Jianjun,Yu Xianbin,Xiong Huan et al. Influence of perforation on the wellbore surrounding rock stress and fracture pressure[J]. Technology Review. 2013, 31(4): 43-48.

[7] HUANG Xiaolan, LIU Jianjun, YANG Chunhe. Borehole stability study of water injection wells in fl uid-solid coupling[J]. Oil Drilling and production technology. 2008, 30(6): 83-87.

[8] Liu Jianjun, Zhang Linzhi, Zhao Jinzhou. Numerical Simulation on Open Wellbore Shrinkage and Casing Equivalent Stress in Bedded Salt Rock Stratum. Scientific World Journal, 2013, Article ID:718196

[9] Xie Jun, Zhu Zheming, Hu Rong, Liu Jianjun. A calculation method of optimal water injection pressures in natural fractured reservoirs. Journal of Petroleum Science and Engineering, 2015,Vol.133:705-7121

[10] Jian-Jun Liu, Xian-Bin Yu, Jin-Zhou Zhao. Numerical simulation of geostress and porepressure evolution around oil or water well under different injection-production ratio. Mathematical Problems in Engineering, Vol.2013, Article number:604748

[11] Gholami R, Rasouli V, Aadnoy B, et al. Application of in situ stress estimation methods in wellbore stability analysis under isotropic and anisotropic conditions[J]. Journal of Geophysics and Engineering. 2015, 12(4): 657.

[12] Yue Ping, Du Zhiming,Chen Xiao fan et al. A Coupling Model of Fishbone Multilateral Horizontal Well in Bottom Water Reservoir [J]. Journal of Southwest Petroleum University (Science & Technology Edition). 2015(04): 117-126.

[13] Liu Jianjun, Song Rui, Zhao Jinzhou. Numerical Simulation Research on Seepage Mechanism in Pore-scale Deformable Porous Media. Disaster Advances, 2013, 6(S1): 49-58

[14] Kanfar M F, Chen Z, Rahman S S. Risk-controlled wellbore stability analysis in anisotropic Formations[J]. Journal of Petroleum Science and Engineering. 2015: L6125.

[15] Wang J, Liu X. Stability Analysis of a Borehole Wall Based on ABAQUS[J]. Computer Aided Drafting,Design and Manufacturing. 2015, 1: 56-61.

[16] He Shiming, Tang Ming, Xiong Jiyou et al. Friction and Torque Control Technology For Slim and Long Horizontal Well[J]. Journal of Southwest Petroleum University (Science & Technology Edition). 2015(06): 85-92.

[17] Yuan Junliang, Deng Jingen, Li Dahua, et al. Calculation of Micro-hole Collapse Pressure in Gas Shale[J]. Tech review. 2013(07): 71-74.

[18] Ji Buzibu. Branch well connected well Sidewall mechanical stability study[D].Southwest petroleum university , 2010.

[19] FAN Kaixiang, LIU Jianjun. The Analysis of Effects of Stress and Deformation on Surrounding Rock of the Well During Groundwater Extraction. Physical and Numerical Simulation of Geotechnical Engineering, 2015, (20):101-113

[20] Jianjun Liu, Rui Song. Numerical Simulation on Hydromechanical Coupling in Porous Media Adopting Three-Dimensional Pore-Scale Model. Scientific World Journal, 2014,Vol.2014, ID:140206

[21] Liu Shenggui, Peng Zhigao, Li Zhongli, et al.Numerical analysis of coalbed methane horizontal branch well stability[J]. Journal of Liaoning Technical University(Natural Science). 2015 (07): 769-773.

[22] Li Xiangchen,Tang Yili,Luo Pingya et al.Simulation study on borehole stability of branchhorizontal wells in coal bed[J]. Oil Drilling and production technology. 2008(06): 42-45.